PREDICTING SEAT BELT USE IN FATAL MOTOR VEHICLE CRASHES FROM OBSERVATION SURVEYS OF BELT USE

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ABSTRACT

There is a large difference between the rates of observed seat belt use by the general public and belt use by motor vehicle (MV) occupants who are fatally injured in crashes. Seat belt use rates of fatally injured occupants, as reported in the Fatality Analysis Reporting System (FARS), are much lower than the use rates found in observation surveys conducted by the states. An important question is suggested by these data: Is there a way to predict FARS use rates based on observed use rates? Development of a model that describes a functional relationship between these rates might provide some theoretical and practical insights concerning seat belt use and the prevention of fatal injuries in MV crashes. We explored the relationship between FARS and observed rates by using two initial assumptions: (a) belt users and nonusers are equally likely to be involved in "potentially fatal collisions" (PFCs), and (b) belts are 50 percent effective in preventing deaths in a PFC. We define a PFC as any collision with sufficiently severe impact forces to kill a non-belted vehicle occupant. These assumptions can be represented as a simple mathematical relationship between the use rates of fatally injured occupants and observed rates as follows: $F = (1 - E)*S / ((1 - S) + (1 - E)*S)$, where F is the FARS rate for each state, E is the effectiveness of belts in preventing fatalities, and S is the observed rate for each state. We examined the fit of this model and the data by comparing each state's actual FARS use rate with the rate predicted by the model. We found that the model does not fit the state data points. We next examined the effects of changing the assumptions in the model. Changing the seat belt effectiveness parameter could not provide a good fit without using an unrealistic assumption, ie, that seat belts are 71 percent effective in preventing fatalities. The inclusion of a risk coefficient for nonbelted occupants provided a reasonable fit of the model to the individual state data points. The major findings of the study were that a simple, straightforward mathematical description of the expected rate of seat belt use by occupants killed in MV collisions does not fit the FARS data, and that a model consistent with the data can be obtained by incorporating the assumption that non-users of seat belts have a higher risk of involvement in potentially fatal collisions than do seat belt users. It was concluded that the unbelted segment of the population is over-represented among occupants killed in MV collisions for two reasons: (a) because of a greater chance of involvement in potentially fatal collisions in the first place, and (b) because they are not wearing seat belts when a collision does occur. There are policy and program implications that follow from this conclusion. Traffic safety interventions targeting non-belt users should focus on two separate and distinct areas; specifically, interventions to increase belt use and interventions to reduce the non-belt users' greater risk of involvement in potentially fatal collisions.

KEYWORDS: FATAL MOTOR VEHICLE CRASHES, FARS, SEAT BELT USE

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INTRODUCTION.

There is a large difference between the rates of seat belt use by the general public and belt use by motor vehicle (MV) occupants who are fatally injured in crashes. Seat belt use rates of fatally injured occupants, as reported in the Fatality Analysis Reporting System (FARS), are much lower than the use rates found in observation surveys conducted by the states. For example, in Washington State the observed rate was 83 percent in 1995 while the FARS rate was 35 percent. Differences between these rates are found in all of the states. The FARS and observed rate data for 1995 are summarized in Table 1 (NHTSA, 1995, for survey data; NHTSA-NCSA, personal communication, for the FARS data).

Deleted: The relationship between safety belt use among fatally injured occupants and general public had been developed in the 80's and early 90's by Evans (1987b) and NHTSA researchers (Partyka, 1987; Partyka and Womble, 1989; Blincoe, 1994; Klein and Waltz, 1995). Much of the earlier interest was, however, in estimation of potential lives saved by increased belt use. Although an underlying relationship between the FARS use rates and observed rates was implied in these earlier studies, a direct explanation of differences between the two rates was not attempted. Today many people acknowledge an importance of wearing safety belts. Many states have accomplished to raise safety belt use rates well beyond the range studied by earlier researchers (i.e., above 75 percent) and virtually every state reports observational belt use survey rates today (except Wyoming). Availability of these surveyed belt use rates and matching FARS use rates for states increases the power of estimation results. ¶

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This study takes a fresh look at the relationship between the FARS rates and observed rates by utilizing all existing data from 1995 FARS data and observational survey data (including the higher range of observed use rates). It attempts to explain, in a simple mathematical relationship, the reason why a state experiences a discrepancy in the two rates. In addition, by incorporating risk factor into the prediction model, this study verifies an existence of so-called "selective recruitment hypothesis" among unbelted, fatally injured occupants. Finally it explicitly derives risk function and quantifies selective recruitment based on the empirical data. ¶

Differences between the observed and FARS use rates are not surprising. Equivalent rates would indicate that belts had no effectiveness in preventing deaths. Conversely, if belts were 100 percent effective, then the use rate of fatally injured occupants would be zero. Given that the effectiveness of seat belts is less than 100 percent, it is expected that some proportion of belted occupants will be killed in crashes. Therefore, the FARS rate should be lower than the observed rate, but the size of the expected difference is uncertain. There are at least three factors that could influence the size of this difference: 1) the degree to which seat belts are effective in preventing deaths, 2) differences in the characteristics of belted and unbelted occupants, and 3) inconsistencies in data definitions and possible biases in the two datasets.

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An intriguing question is suggested by the use rate data: Can the FARS rate be predicted from the observed rate? Development of a mathematical model that describes a functional relationship between the rates might provide some theoretical and practical insights concerning seat belt use and the prevention of fatal injuries in MV crashes. The converse of this question also has some important implications: Can the use rate in observation surveys be predicted by the FARS rate? One practical application of this could be development of an inexpensive and readily available assessment tool to measure progress in seat belt use nationally as well as within individual states.

The relationship between safety belt use among fatally injured occupants and the general public was explored in the 1980's and early 1990's by Evans (1987b) and NHTSA researchers (Partyka, 1987; Partyka and Womble, 1989; Blincoe, 1994; Klein and Waltz, 1995). Much of the earlier interest, however, was estimating potential lives saved by increased belt use. Although an underlying relationship between the FARS and observed rates was implied in these earlier studies, a direct explanation of differences between the two rates was not attempted. Our study takes a fresh look at this relationship. The present data (1995) also represent a higher range of observed belt use than was analyzed in earlier studies. The purpose of our study is to investigate, with a mathematical model, the reason why there is a difference between the two rates. Our approach is to initially compare a simple (straw man) model with the data, and to establish that this model cannot account for the data, even after biases in the datasets are accounted for. Possible modifications of the model are then examined in an attempt to produce a better fit between the model and the data.

METHOD

We began exploring the relationship between FARS and observed rates by using two simplifying assumptions: (a) belt users and nonusers are equally likely to be involved in "potentially fatal collisions" (PFCs), and (b) belts are 50 percent effective in preventing deaths in a PFC. We define a PFC as any collision with sufficiently severe impact forces to kill a non-belted occupant. It should be noted that previous studies have found belts to be about 45 percent effective in preventing fatalities (Evans, 1986; Partyka, 1988; Blincoe, 1994). We initially use an effectiveness value of 50 percent to simplify discussion, but calculations use the 45 percent value. These assumptions can be intuitively explained by the following example:

1. In a state with 80 percent observed belt use, and where both belted and non-belted occupants are equally likely to be involved in a PFC, it is expected that out of every 100 occupants in PFCs, there will be 20 who are unbelted. These 20 persons are killed.
2. Of the 80 belted occupants, 40 will survive and 40 will be killed, assuming seat belt effectiveness of 50 percent.
3. Then, of the total of 60 occupants who were killed, 40 were wearing belts, yielding a rate of 66.7 percent belt use among fatally injured occupants.

This example can be represented as a mathematical relationship between the use rates of fatally injured occupants and observed rates. The FARS rate is a function of the observed rate and a parameter representing the effectiveness of belts, as shown below:

$F = (1 - E)*S / ((1 - S) + (1 - E)*S)$ ....Eq. (1)

Where: F is the FARS rate (number of belted fatalities divided by all fatalities,

E is the effectiveness of belts in preventing fatalities, and

S is the observed rate.

The model uses the expression “$(1 – E)*S$” to represent belted occupants who died and “$(1 – S)$” to represent unbelted occupants who died. In terms of the previous example:

$(1 – E)*S = 50\% * 80\% = 40\%$, and

$(1 – S) = (100\% - 80\%) = 20\%$,

so that $F = 40\% / (20\% + 40\%) = 66.7\%$.

RESULTS.

We examined the agreement between this model and the data by comparing each state’s FARS rate with the rate predicted by the state’s observed seat belt use. We found that the model does not fit the data points. Figure 1 shows the model superimposed on a scatter plot of the FARS rates as a function of observed rates. The data points for all of the states are lower than the rates predicted by the model. The predicted values are listed in Table 1 under the column heading “Predicted, E = .45”. The degree of correspondence between the data and the model was measured by computing the sum of the squared differences (SSD) between the predicted and actual rates. (Values close to zero represent close agreement between the model and the data.) The SSD equaled 2.43 for this model. The lack of agreement between the model and the data could be due to either bias in the data or an erroneous assumption in the model. Both of these possibilities were examined.

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We discounted the possibility of bias in the FARS belt use data because of the exhaustive nature of police investigations in fatal collisions. Law enforcement procedures in most states are to bring in officers with advanced training when investigating fatal collisions. Investigations of fatal crashes are methodical and are supported by forensic examination. Physical evidence of belt use usually is obvious and detectable, as are injuries consistent with non-use.

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The extent of bias in state survey data is problematical because of a lack of information on the survey methods used by different states. It should be noted, however, that the 1996 national estimate of belt use derived from state surveys (68%) falls within the 95 percent confidence interval of the 64.4 percent rate from the National Occupant Protection Use Survey (NHTSA, 1999). Discussion with NHTSA personnel suggest that the most likely sources of consistent bias in state surveys are the seating positions of the occupants observed and hours of the day when the surveys are conducted.

Observation surveys are typically conducted only during daylight hours, while the FARS data are based on all hours of the day. It is likely that belt use rates are higher during the day than at night. In fact, 1995 national FARS data show that the daytime (6AM to 6PM) rate was 39.6 percent as compared to the nighttime (6PM to 6AM) rate of 23.7 percent. Thus, direct comparison of the FARS rates (for all hours of the day) and observed rates is inappropriate because of daytime bias in the observation data. To provide for a more valid comparison, we computed the 1995 daytime FARS rates for each state and then tested the model against these data. Figure 2 shows the model compared to the daytime FARS rates and Table 1 summarizes these data. The fit between the model and data is improved, but the lack of correspondence still is apparent. The SSD value was 1.19, as compared to 2.43 found in the 24-hour FARS data.

Next, we adjusted the FARS data to account for occupant seating positions. State observation surveys typically include front seat occupants only, while the FARS data are based on all seating positions. We computed the daytime FARS rates for front seat occupants and again tested the fit between the model and data. Figure 3 shows the model compared to the daytime/front seat occupant FARS rates and Table 1 summarizes these adjusted data. The fit of the model is improved, but there still remains a substantial discrepancy between the data and model. The SSD value was 1.03 as compared to 1.19 with daytime FARS data for all occupants.

Since adjustment for daytime and seating position biases in the data cannot account for the discrepancy between the predicted and actual use rates, we next attempted to modify the model to fit the data. The initial assumption about seat belt effectiveness was examined first. The effectiveness parameter was systematically increased above 45 percent, and each revised model was compared with the daytime/front seat FARS data. Figure 4 shows the best-fit model based on an iterative process of testing different values. The sum of squared differences was minimized (SSD = 0.37) using an effectiveness value of 67 percent. The predicted values are listed in Table 1.

The next stage of our analysis examined the assumption that belted and nonbelted occupants are equally likely to be involved in PFCs. It is well documented that certain behaviors, such as speeding, intentional risk taking, aggressive driving, and impaired driving are associated with increased risk of MV collisions and that individuals engaging in high-risk behaviors are less likely to use belts than are low-risk persons (Evans and Wasielewski, 1983; Wasielewski, 1984; Preusser, et al. 1991; Hunter, et al. 1992; Winnicki, 1997; Dee, 1998). It has also been shown that non-belt users in a state with a high use rate possess distinct risk characteristics, such as prior convictions, arrests, crash experience, and speeding (Reinfurt et al., 1994).[1]

To incorporate these findings in the model requires an assumption that non-belted occupants are over-represented in PFCs. The unbelted component in the model (1 – S) was multiplied by a coefficient representing increased PFC involvement; ie, R*(1 – S), where R is the risk coefficient. The model now specifies that non-belted occupants are "R" times more likely to be involved in a PFC than are belted occupants. This modification is shown below. (The effectiveness value used was E = 45 percent.)

$F = (1 - E)*S / (R*(1 - S) + (1 - E)*S)$ ....Eq. (2)

To test this risk model, we again used a process of iteration. Different values for the risk parameter were systematically entered into the model. We found that a value of R = 1.66

yielded the best fit with the data and minimized the sum of squared differences (SSD = 0.37). Figure 5 shows the risk model and the FARS daytime use rates for front seat occupants. The predicted values are listed in Table 1.

One problem with this revised model, however, is that there is a tendency for the data points to be above the curve for low belt use states and below the curve for high belt use states. This would suggest that high rates of observed belt use might be related to lower than expected belt use by fatally injured occupants, ie, an increased risk of PFCs for unbelted occupants could be correlated with the rates of observed belt use.

It seems reasonable to speculate that in all states there may be a roughly constant proportion of the population at high-risk for PFC involvement. These high-risk individuals also are very unlikely to use belts. It follows, then, that the *proportion of non-belted MV occupants* that are high-risk should be small in a low belt use state and large in a high belt use state. For example, if high-risk individuals comprise 10 percent of the total population and observed belt use is 40 percent, then 10 out of 60 non-belt users would be in the high-risk group. In contrast, if observed use was 70 percent, then 10 out of 30 unbelted occupants would be high-risk. Thus, the relative proportion of high-risk individuals among unbelted occupants would be greater in a high belt use state.

This discussion suggests that the constant 1.54 risk factor found in the previous model could, in fact, be a variable risk factor; ie, there would be a larger risk coefficient in a high belt use state and a smaller risk coefficient in a low use state. To explore this possibility, a relative risk model was developed where the over-representation of unbelted occupants in PFCs is inversely related to the percentage of unbelted occupants. Relative risk was defined as a constant (equal to one) plus the ratio of a risk coefficient to the percentage of unbelted occupants, as shown in the following expression:

$R = 1 + A/(1 - S)$ .... Eq. (3)

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[1] A high-risk passenger would include any person traveling in a vehicle driven by an unsafe driver, although it is plausible that certain behaviors by a passenger could

Where: A is a coefficient representing risk in the model, and
(1 – S) is the percentage of unbelted occupants.

Substituting Eq. (3) into Eq. (2) yields a variable-risk model as shown below:

$F = (1 – E)*S / ((1 + A/(1 – S))*(1 – S) + (1 – E)*S)$ .... Eq. (4)

We examined the fit of this variable risk model (Eq. 4) to the daytime front-seat occupant FARS data points. We again used an iterative process of testing different values of A. The value A = 0.19 maximized the fit of the model to the data (SSD = 0.25). Figure 5 summarizes this variable risk model, and Table 1 shows the rates predicted by the model.

The increased risk associated with unbelted occupants in this model is based on a risk component that increases as observed belt use rate increases. For example, in a state with 70 percent belt use, the risk factor would be R = 1 + .19/.30 = 1.63, and a state with 40 percent use would yield R = 1 + .19/.60 = 1.32. The mean of the computed risk coefficients among the states was 1.58, and the values ranged from 1.32 to 2.36. this mean risk value of 1.58 is in close agreement with the coefficient of 1.54 found for the constant risk model.

DISCUSSION AND CONCLUSIONS

The initial model examined in this paper, although seeming to have some face-validity, incorporated a simplifying assumption that both users and non-users of seat belts are equally likely to be involved in a potentially fatal collision. Since this assumption is not consistent with studies showing belt use to be related to risky driver behaviors (eg, Hunter et al, 1993), this initial model can be regarded as a “straw man”. We found that the model did not fit the FARS data points (SSD = 2.43), neither when daytime bias in

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potentiate the risk-taking behavior of a driver.

the data was accounted for (SSD = 1.19), nor when occupant seating position was also accounted for (SSD = 1.03).

Changing the seat belt effectiveness parameter in the model improved the fit with the FARS data for daytime hours and front seat occupants (SSD = 0.37). This revised model required an effectiveness value of 67 percent which is inconsistent with the findings of earlier research showing that seat belts are roughly 45 percent effective in preventing fatalities (Evans, 1986; Partyka, 1988). However, a more recent study (Rivara, 2000) found that manual lap-shoulder belts were 73 percent effective in preventing fatalities (odds ratio of 0.27 when adjusted for occupant age and sex, vehicle model year, airbag deployment, delta-V, and principle direction of force).

Next, modifying the model to include a risk coefficient for nonbelted occupants produced a reasonable fit with the individual state data points (SSD = 0.37). Finally, modification of the model to incorporate risk as a variable component further improved the fit of the model and data (SSD = 0.26).

We assert, based on this model and the findings of previous studies, that unbelted occupants are more likely to engage in risky driving behaviors than are belted occupants. We also suggest that it is their dangerous driving behavior, per se, rather than non-use of belts, that leads to an over-representation in potentially fatal collisions.

Even though the risk model produces a reasonable fit with the data, there are other alternatives that should be considered. The overrepresentation of non-belt users in PFCs could simply reflect greater exposure. Data addressing this issue are conflicting. Self-reported annual mileage did not differ between drivers who had been observed wearing or not-wearing belts in the Preusser et al (1991) study, while Reinfurt et al (1994) found significantly higher annual miles of travel for unbelted drivers (17,660 vs 15,470 miles). However, Hunter et al (1993) reported that the driving records of unbelted drivers were worse than belt users, even when controlling for annual miles and demographic characteristics. Thus, it seems unlikely that the driving exposure of unbelted occupants would be of sufficient magnitude to account for a roughly 50 percent higher (R = 1.54) involvement in potentially fatal collisions.

Another (related) alternative is that unbelted occupants have greater exposure during times of the day and/or on the types of road environments where PFCs are more likely to occur. The possibility of differential exposure to nighttime driving was controlled in that the FARS data used in our analysis was limited to daytime hours. However, differential exposure to driving on dangerous roads cannot be excluded from consideration, and this would seem to be a hypothesis worthy of future research. We would suggest, however, that a finding of greater exposure on dangerous roads would be consistent with the hypothesis that unbelted occupants engage in more risky driving than do belted occupants.

It should be emphasized that the intent of this paper was not to find the idealized model that provides the mathematically optimum fit with the data points, but rather to elaborate some theoretical constructs that produce a model consistent with the empirical relationship between observed belt use and use by fatally injured occupants. It is possible that the optimum model could require an effectiveness coefficient and/or a risk coefficient different than the ones we obtained in our analysis.

The major findings of the present analysis are: (1) that a simple (straw man) model of the expected rate of seat belt use by occupants killed in MV collisions does not fit the FARS data, and (2) that a model consistent with the data can be obtained by incorporating the assumption that non-users of seat belts have a higher risk of involvement in potentially fatal collisions than do seat belt users.

Our analysis suggests: (1) that unbelted occupants are, on average, about 1.5 times more likely to be in a potentially fatal collision than are seat belt users, and (2) that the relative risk is higher in states with high belt use rates. Obviously, these assertions are limited to the daytime hours that were used in our analysis. It is not unreasonable to infer, however, that the risk associated with unbelted occupants would be even higher during night hours, given the greater prevalence of impaired driving at night.

We conclude that the unbelted segment of the population is over-represented among occupants killed in MV collisions for two reasons: (a) because of a greater chance of involvement in potentially fatal collisions in the first place, and (b) because they do not have the protection of seat belts when a collision does occur.

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There are policy and program implications that follow from this conclusion. Traffic safety interventions targeting non-users of belts should focus on two separate and distinct areas; specifically, (1) interventions designed solely to increase belt use and (2) interventions directed at reducing the non-user's greater risk of involvement in potentially fatal collisions.

The behavior of non-use of belts could be used by law enforcement as a factor to identify dangerous drivers. A seat belt violation may be an indicator; somewhat akin to the presence of a radar detector in the vehicle of a driver stopped for speeding. A driver's action of not wearing a belt could be viewed, by itself, as an indication of additional dangerous driving behaviors. This implies that a primary enforcement seat belt law, in addition to raising belt use rates among the population as a whole, also could be an appropriate countermeasure that police officers could use to target their enforcement efforts towards the high-risk driver.

In addition, remedial interventions by the courts or licensing authorities may be appropriate for individuals who commit seat belt violations. Such interventions could focus on high-risk driving behaviors in addition to addressing occupant restraint issues.

Public information and enforcement programs intended solely to encourage the use of seat belts could also have an indirect impact on high-risk driving behavior. The experience of being stopped by a police officer for not wearing a seat belt might change the driver's perception of the chances of being stopped at other times for other offenses. A seat belt ticket would reinforce this message.

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